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On energy for sustainable development in Nigeria

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ABSTRACT

The fuel driving the engine of growth and sustainable development of any nation is the nation's access to reliable and adequate energy. Access to energy is a crucial enabling condition for achieving sustainable development. Prudent energy policies and research can play an important role in steering both industrialized and developing countries onto more sustainable energy development paths. Specifically, they can strengthen the three pillars of sustainable development: the economy, by boosting productivity; social welfare, by improving living standards and enhancing safety and security; and the environment, by reducing indoor and outdoor pollution and remediating environmental degradation. Many factors that need to be considered and appropriately addressed in moving towards energy sustainability in Nigeria are examined in this article. These include full exploitation and promotion of renewable energy resources and application of energy conservation measures in various sectors such as manufacturing industrial set-up, office and residential buildings and transportation.

Contents

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1. Introduction

The term 'sustainable development' has been popularized by the World Commission on Environment and Development (WCED), in its 1987 report entitled, 'Our Common Future'. The commission defined sustainable development as 'the development that meets the needs of the present without compromising the ability of future generation to meet their own needs' [39]. Sustainable development stands on three pillars in terms of its definition for the 2002 World Summit on Sustainable Development (WSSD): social development, economic development and environmental development.

Sustainability is a critically important goal for human activity and development. Sustainability in the area of energy is of great important to any plans for overall sustainability given (i) the pervasiveness of energy use, (ii) its importance in economic development and living standards, and (iii) the significant impacts that energy processes and systems have had, and continue to have, on the environment.

Sustainable development is increasingly becoming a goal, to which numerous countries throughout the world aspire [35]. Overall sustainability has been defined in many ways and is often considered to have three distinct components: environmental sustainability, economic sustainability and social sustainability. Overall sustainable development in general requires the simultaneous achievement of environmental, economic and social sustainability. Achieving this balance is indeed a challenging.

Although energy is not directly one of the three components of sustainability cited above, it is indirectly linked to each. That is, energy resources drive much if not most of the world's economic activity, in virtually all economic sectors, e.g. industry, transportation, residential, commercial, etc. Also, energy resources whether fossil fuels or renewables, are obtained from the environment, and wastes from energy processes (production, transportation, storage, utilization) are typically released to the environment. Finally, the services provided by energy allow for good living standards, and often support social stability as well as cultural and social development. Given the intimate ties between energy and the key components of sustainable development, it is evident the attainment of energy sustainability is a critical aspect of achieving sustainable development, in individual countries and globally.

In this paper, sustainable energy is taken in a broader context to include important factors such as resource development, existing energy infrastructure, and development needs. The debate on sustainable energy led to the agreement at 9th session of the UN Commission on Sustainable Development (CSD-9), which was further endorsed at the 2002 World Summit for Sustainable Development (WSSD) held in Johannesburg, South Africa, that 'sustainable energy' be regarded as 'energy for sustainable development'. It is aptly covered by the following definition [28]:

> Sustainable energy is defined as energy providing affordable, accessible and reliable energy services that meet the economic, social and environmental needs within the overall developmental context of the society for which the services are intended, while recognizing equitable distribution in meeting those needs.

Energy is essential for economic and social development. About 90% of the world energy supplies are provided by fossil fuels, with the associated emissions causing local, regional and global environmental problems [33]. Most energy projections show that current and expected future global energy demand patterns are not sustainable. Even when assuming massive improvements in energy intensity, long term projections indicate that world energy demand may increase dramatically, with most of this increase, taking place in developing countries. These trends indicate that, in order to comply with the necessary conditions for the three dimensions of sustainability (economic, environmental and social) with respect to energy production and consumption, a decoupling of economic activity from fossil primary energy consumption should be achieved [34].

Increasing the share of renewable energy sources (RES) in the energy balance enhances sustainability and helps to improve the security of energy supply by reducing dependence on imported energy sources. In addition, the development of energy efficiency (EE) is a central aim of the world energy policy in order to contribute in reducing greenhouse emissions [31].

The interest in RES and EE increased when the oil crises of the 1970s made everyone aware of the fact that fossil resources would run out 1 day – but since there is some uncertainty about when that will actually happen the efforts made in this area remain rather tentative.

Nowadays, growing environmental concerns and limitations in the exploitation of conventional energy resources have given new impulse in modern RES technologies. Beyond 2020, new technologies, such as hydrogen-based fuel cells and carbon sequestration, hold out promising prospects of plentiful, clean energy supplies for the world. So RES projects and EE will need to play a greater role in the future energy mix in order to achieve low-carbon intensive energy systems and energy sustainability (European Climate Change Programme (ECCP) Progress Report, [30]).

This paper outlines and reviews some of the most important energy conservation opportunities and renewable energy options in Nigeria, discuss their relative potential and attractiveness to build a truly sustainable, long-term, energy future in the country.

2. General features of energy economy in Nigeria

Energy is the mainstay of Nigeria's economic growth and development. It plays a significant role in the nation's international diplomacy and it serves as a tradable commodity for earning the national income, which is used to support government development programmes. It also serves as an input into the production of goods and services in the nation's industry, transport, agriculture, health and education sectors, as well as an instrument for politics, security and diplomacy [36].

Energy, and in particular, oil and gas, has continued to contribute over 70% of Nigeria's Federal revenue national development programmes, and security, depend largely on these revenue earnings. Energy, especially crude oil has over the past 5 years contributed an average of about 25% to Nigeria's Gross Domestic Product (GDP), representing the highest contributor after crop production. The contribution of energy to GDP is expected to be higher when we take into account renewable energy utilization, which constitutes about 90% of the energy used in rural population [1].

Nigeria is richly blessed with primary energy resources. The country is endowed with the world's tenth largest reserves of crude oil currently estimated to be about 36 billion barrels (about 4.896 billion tonne of oil equivalent (toe)) in 2006. The country has also been described as more of a natural gas island than oil with an estimated endowment in 2006 put at about 166 trillion standard cubic feet (5210 billion m^3). This includes associated and non-associated reserves, placing Nigeria among the top ten countries with the largest gas reserves in the World. Other significant primary energy resource endowment in Nigeria include: Tar sands – ~31 billion barrels oil equivalent (4.216 billion toe); coal and lignite – estimated to be ~2.7 billion tonnes (1.882 billion toe); Large Hydropower Potentials ~10,000 MW; Small Hydropower Potentials, provisionally estimated to be ~734 MW. Table 1 provides a

Table 1
Nigeria's energy reserves and potentials (2005).

Resource type	Reserves	Reserves (BTOE)[a]
Crude oil	36.0 billion barrels	4.896
Natural gas	166 trillion SCF[b]	4.465
Coal and lignite	2.7 billion tonnes	1.882
Tar sands	31 billion barrel of oil equivalent	4.216
Sub-total fossil		15.459
Hvdropower, large scale	10,000 MW	
Hydropower, small scale	734 MW	
Fuelwood	13,071,464 ha[c]	
Animal waste	61 million tonnes/year	
Crop residue	8.3 million tonnes/year	
Solar radiation	3.5–7.0 kWh m^{-2} day^{-1}	
Wind	2–4 m/s (annual average)	

Source: Dayo [2].
[a] BTOE, billion tonnes of oil equivalent.
[b] SCF standard cubic feet.
[c] Forest land estimate for 1981.

brief summary of these endowments in Nigeria. The table contains recent estimates of other renewable potentials apart from hydropower [2].

Despite the ample coal, oil and natural gas reserves, at the present rate of extraction, it has been estimated that, these reserves, by the next 40 years, will be depleted to the point where it would be uneconomical to continue exploration. It becomes imperatives, therefore, that we start implementing energy conservation and efficiency measures in conversion systems while looking for alternative source of energy [29].

2.1. Energy crises in Nigeria

Throughout the world electricity is the most widely used and desirable form of energy. It is a basic requirement for economic development and for an adequate standard of living. As a country's population grows and its economy expands its demand for electrical energy multiplies. If this demand is not met adequately a shortage in supply occurs. This shortage can assume crisis proportions. According to Chigbue [3], electric power as a major component in the requirements for effective industrialization and development is grossly inadequate in Nigeria.

For many years now, Nigeria has been facing an extreme electricity shortage. This deficiency is multi-faceted, with causes that are financial, structural, and socio-political, none of which are mutually exclusive [4]. At present, the power industry in Nigeria is beset by major difficulties in the core areas of operation: generation, transmission, distribution and marketing [5].

In spite of Nigeria's huge resource endowment in energy and enormous investment in the provision of energy infrastructure, the performance of the power sector has remained poor, in comparison with other developing economies. This assertion was confirmed by a World Bank [38] assessment study conducted on energy development in Nigeria, which compared the performance of Nigeria's power sector with those of 20 other developing countries. The study reveals that the sector had the highest percentage of system losses at 33–41%; the lowest generating capacity factor 20%; the lowest average revenue at US$ 1.56 kWh; the lowest rate of return at 8%; and the longest average accounts receivable period of 15 months.

Thus, the ability of the distribution of power system to perform its function under stated conditions for a period of time without failure is called Distribution System Reliability (DSR) [37]. System Average Interruption Duration Index (SAIDI) is one of the DSR indices used in the assessment of distribution performance [6]. It represents in minutes, the annual average total duration of electric power interruption to a customer. This reliability index is embarrassingly high in Nigeria as shown in Table 2. The Manufacturers' Association of Nigeria (MAN) reported Nigeria SAIDI of 60,000 min or greater than, seems to be more realistic as it agreed with a figure of 87,639 min obtained in another independent research [32]. This is in spite of the fact that only about 40% of the 140 million Nigerians have access to electricity [40].

Table 2
SAIDI for some countries.

Country	SAIDI (min)
France	52
Singapore	≈1.5
USA	88
Nigeria (PHCN)	900
Nigeria (MAN study)	>60,000

Source: Ogujor and Orobor [40].

This high SAIDI had resulted to poor per capita electricity consumption of 125 kWh in Nigeria as against those of South Africa, Brazil and China estimated as 4500 kWh, 1934 kWh and 1379 kWh respectively.

There is no doubt that expensive and unreliable power remains a major concern to all sectors of the economy in Nigeria: the industrial, commercial, and domestic sectors especially. Multiple and unpredictable power cuts, which have become a daily occurrence in Nigeria, often result in equipment malfunctioning, which make it difficult to produce goods and provide service efficiently. As a result of this fundamental problem, industrial enterprises have been compelled to install their own electricity generation and transmission equipment, thereby adding considerably to their operating and capital costs [41].

Most businesses in Nigeria, large and small, end up relying on the generator for electricity to power their businesses. MTN – the South African mobile phone company and the largest mobile phone supplier in Nigeria – is estimated to 'have installed 6000 generators to supply its base stations for up to 19 h a day. The company spends $5.5 million on diesel fuel to run the generators' [41].

Enweze [7] has estimated that about 25% of the total investments in machinery and equipment by small firms, and about 10% by large firms, were on power infrastructure. Despite the attempts by some firms to supplement the power supply by PHCN, electricity demand by consumers, particularly domestic users has continues to increase.

2.2. The Nigerian energy sector today

Nigeria has significant energy resources, including over 36 billion barrels of oil, 187 trillion cubic feet of gas and 4 billion metric tonnes of coal and lignite. The country also has a large amount of renewable energy resources including hydro electricity, solar, wind and biomass energy. Hydro resources (small and large hydropower) are estimated at 14,750 MW, solar radiation is estimated at 3.5–7.0 kWh m^{-2} day^{-1}, wind energy potential of 150,000 terra joule per year (generated by an average wind speed of 2.0–4.0 m/s) and biomass at 144 million tonnes per year [42].

Despite the large reserves of energy resources available in the country, the levels of energy consumption have been very low relative to other countries with comparable energy resources and population figures. In 2004, about 776.9 kgoe of energy per capita (population of 140 million) were consumed as against about 2596.9 kgoe of energy per capita consumed by South Africa (population of 44 million). This low energy consumption is caused by the recurrent scarcity of petroleum products and the persistent electricity black outs which have resulted in a high reliance on self generated electricity. Fig. 1 shows Nigeria's energy per capita in comparison with some select developing countries [40,42].

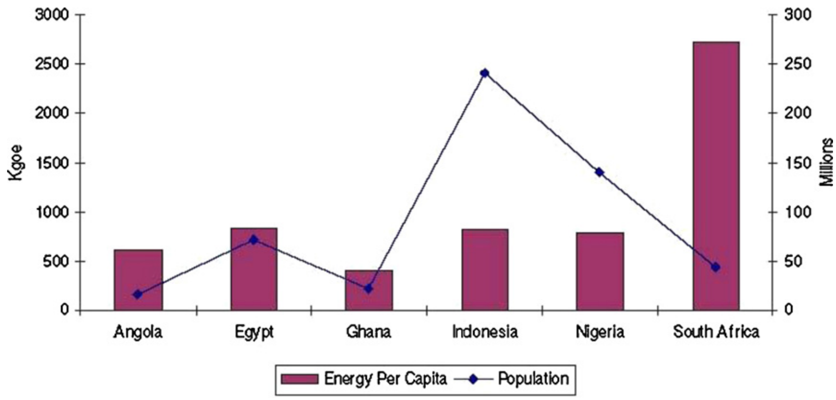


Fig. 1. Comparison of energy per capita for select countries, 2004.

Source: EIA [27].

The energy mix of Nigeria is dominated by oil which accounts for about 57%, followed by natural gas (36%) and hydroelectricity (7%) as of 2005. Other energy sources such as coal, nuclear and renewable energies currently play no significant role in the country's energy consumption mix. Between 1980 and 2005, the share of oil in energy mix decreased from 82% to 56%. Natural gas consumption increased from 9% to 35%. Hydroelectricity experienced a slight increase from 6.6% to about 7% [42].

Over the period of 1989–2005, the share of non-commercial energy in total energy consumption fluctuated within the range of 30–40%. About 95% of total fuel wood consumption falls to households for cooking and domestic industrial activities, which are closely related to household activities. A smaller proportion of the fuel wood and charcoal consumed are used in the service sector [42].

Electricity in Nigeria is supplied through large-scale thermal power and hydroelectric power plants and a 330 kV and 132 kV nationwide transmission network through the Power Holding Company of Nigeria (PHCN). Power demand developed from 3233 MW in 2002 to 3479 MW in 2003 and 3403 MW in 2004. The maximum power demand in 2003 exceeded the available capacity of 3477 MW in 2005. The Government has clearly fallen short of the national targets defined in the National Economic Empowerment and Development Strategy (NEEDS) in order to increase the generation capacity of power facilities to 10,000 MW, the transmission capacity to 9340 MVA and the distribution capacities to 15,165 MVA by the year 2007. Most of the generating facilities are old and outdated, yet cannot be overhauled due to the lack of reserve capacity. This situation was caused by insufficient maintenance, the suspension of new investments and the high rate of auto-generation as a result of frequent large-scale blackouts [43].

The residential sector accounted for 63% of the total electricity consumption in 2005, followed by the commercial sector (27%) and the industrial sector (10%). Natural gas dominates the electricity generation mix, accounting for an average of 63% of the total power generation. After natural gas, hydro is also a significant factor in power generation, though its contribution has decreased. Fig. 2 presents the evolution of the total power generation shares by type of fuel [8].

Meanwhile, the contribution of oil, though marginal since 1980, has also drastically decreased contributing as little as 3% to the total power generation in 2004. In Nigeria, the problems in the Niger Delta have often affected the supply of gas to the power stations leading to major disruptions in electricity generation. Occasional low levels of water in the hydrostations together with the gas disruptions lead to blackouts in most parts of the country. Energy prices in Nigeria are very low compared to other countries and relative to the marginal cost of production. The average electricity tariff in Nigeria is about 6.75 N per kWh (approximately 5 €-Cents per kWh). It is estimated that the generation cost of electricity from winds power in Nigeria is about 8–10 €-Cent per kWh. The current electricity prices (as of November 2008) vary between 3 and 5 €-Cents per kWh [9].

Nigeria's daily energy consumption is 109.6 kWh (per 1000 persons) [42]. On a comparative basis, Nigeria energy consumption is low (Table 3). Though energy consumed by wood fuels is not accounted for, it still remains a dominant source of energy in Nigeria. It is estimated that it could account for as high as 77% of total energy consumed by the household sector in Nigeria.

2.3. Trends in demand for energy in Nigeria

There is an increasing demand for fuel energy due to the increase in economic development and civilization all over the world. Industry is one of the most important energy consuming sectors in the world. According to Mitchel [10], energy is essential to our way of life. It provides us with comfort, transportation, and the ability to produce food and material goods. Historically, energy consumption has been directly related to the gross national product (GNP), which is a measure of the market value of the total national output of goods and services [11].

According to Sambo et al. [44], population is a major driver of energy demand while its most important determinant is the level of economic activity and its structure measured by the total Gross Domestic Product (GDP) alongside with its shares by the various sectors and sub-sector of the economy. Population projection of Nigeria was expected to grow from 115.22 million in 2000 to 281.81 million by 2030 at an average annual rate of 2.86% between 2000 and 2030.

There has been a large number of forecasting projecting world energy for the next few decades. Hubert [45] did some studies in this regard. The projected annual energy growth rate ranges from 2.5 to 4%. World total energy growth slightly exceeds that of US with a growth rate currently over 4%. There have been projections by the International Energy Agency (IEA) and the Energy Information Administration (EIA) that world oil production will have to be increased by about 30% on the current production rate to meet rapidly rising demand [46]. IEA further projected a rise in oil demand from 76 million *b*/*d* in year 2000 to 94 million *b*/*d* in 2010 [47]. If an oil production increase of this magnitude should occur and unexpected reserve are not found, the 95 million bid rate could be sustained for only additional 20–25 years before a depleting world oil resource base would force production down.

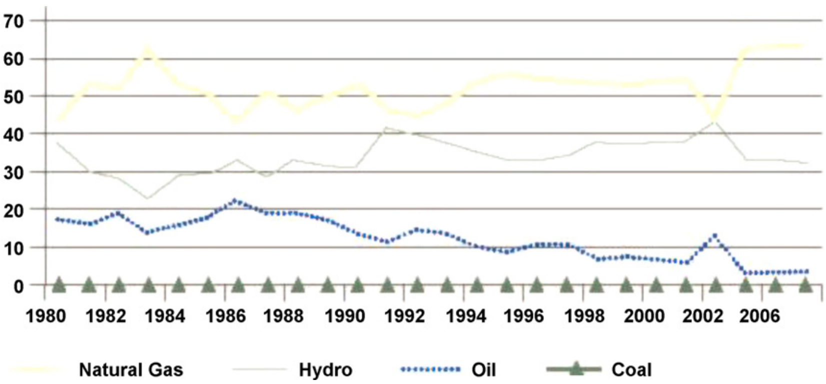


Fig. 2. Share of energy sources in total power generation (%).

Source: World Bank, as of 2006.

Table 3
Comparison of daily energy consumption for select countries.

Country	Daily energy consumption (kWh per 1000 persons)	Daily petroleum fuel consumption ('000 barrels)	Petroleum fuel consumption (barrels per 1000 persons)	GDP 2006 ($ billions)	Annual GDP growth rate % (2005)	Average annual growth 1990–2001
Egypt	1276	538	7.61	107.18	4.96	4.5
Indonesia	496	1022	4.42	364.4	5.6	3.8
India	460	2000	1.91	906.26	9.23	5.9
S. Africa	5487	482	11.04	254.9	4.87	2.1
Nigeria	109.5	257	1.98	114.68	6.94	2.5
Ghana	301	31	1.53	12.9	5.9	4.2
Brazil	2116	2200	12.50	1067.96	2.3	2.8

Source: National Technical Working Group [42].

Based on the models developed by Energy Commission of Nigeria (ECN) to analyze the country's energy sector for the period from 2000 to 2030 with the use of Model for Analysis of Energy Demand (MAED) and Wien Automatic System Planning (WASP) package (Table 4). It can be said that the energy demand of Nigeria will be approximately 2.5, 3, 3.5 and 4.5 folds between the years 2000 and 2015 and approximately 8, 13, 17 and 22.5 folds between the years 2000 and 2030 based on 7% (reference), 10% (high growth), 11.5% (optimistic) and 13% (optimistic) GDP growth rate per annum, respectively. This increase in demand for energy is due to the high level of economic activities expected in Nigeria as measured by the total GDP.

The trends of projected energy demand are shown in Fig. 3. In 2005, the total energy demand based on 10% GDP growth rate revealed that household segment had the largest share of all the sectors. The sectoral energy demands in the 2030 plan period however, showed the highest growth rates for the industrial, followed by the services, household and transport sectors in that order (Table 5). The electricity demand extracted from the total energy demand, shows an increasing trend from the base year 2005–2030 on the four adopted growth scenarios respectively as shown in Fig. 4, indicating a high economic growth rate leading to a substantial increase in electricity demand. The energy consumed over the years shows a decreasing trend with increasing population, necessitating a corresponding increase in energy output. Hence, the country's large energy efficiency potential needs to be exploited (Table 6). In 2007, the total primary energy consumed was 11.4 million tonnes of oil equivalent (mtoe) with petroleum products having the largest share of 67.3% of the total consumption amounting to a total average consumption of 78.7% between 2002 and 2007. This level of consumption was followed by that of hydropower at 23.9%, natural gas at 8.7% and coal at 0.05%

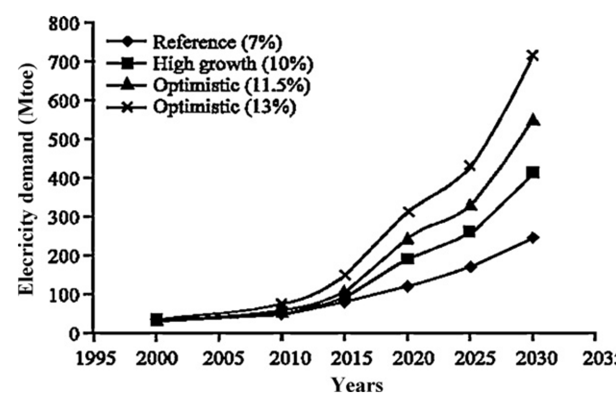


Fig. 3. Graph showing the projected electricity.

Table 4
Total projected energy demand (mtoe).

Scenario	2000	2010	2015	2020	2025	2030
Reference (7%)	32.01	51.40	79.36	118.14	169.18	245.19
High growth (10%)	32.01	56.18	94.18	190.73	259.19	414.52
Optimistic (11.5%)	32.01	56.18	108.57	245.97	331.32	553.26
Optimistic (13%)	32.01	72.81	148.97	312.61	429.11	715.70

Source: Energy Emission of Nigeria (2006).

Table 5
Total energy demand based on 10% GDP growth rate (mtoe).

Kan	2005	2010	2015	2020	2025	2030	Average growth rate (%)
Industry	8.08	12.59	26.03	39.47	92.34	145.21	16.2
Transport	11.70	13.48	16.59	19.70	26.53	33.36	4.7
Household	18.82	22.42	28.01	33.60	33.94	34.27	2.6
Services	6.43	8.38	12.14	15.89	26.95	38.00	8.7
Total	45.01	56.87	82.77	108.66	179.75	250.84	8.3

Source: Energy Emission of Nigeria (2008).

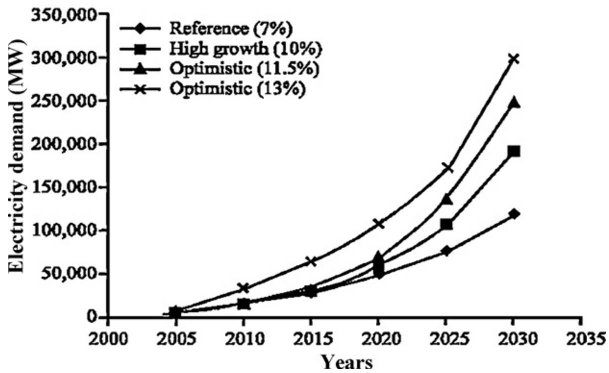


Fig. 4. Graph showing the projected demand between 2000 and 2030 electricity demand between 2005 and 2030.

Table 6
Per capita primary energy consumption in Nigeria.

	Energy consumed (mtoe)	Population (million)	Per capita energy consumption (toe/capita)
2002	18.783	122.365	0.153
2003	19.106	126.153	0.151
2004	16.267	129.927	0.125
2005	17.707	133.702	0.132
2006	12.421	140.003	0.089
2007	11.387	144.203	0.097

Source: CBN (2006, 2007) and NSB (2007).

with their respective total average consumption standing at 16.08, 5.17 and 0.04% for the 2002–2007 periods as shown in Table 7. Flaring, adversely reduced the maximum contribution of natural gas to the total energy consumption mix in spite of its huge deposit in the country because most of the oil fields lack appropriate infrastructure for gas production and the general Niger Delta security issue (bunkering, sabotage, etc.) have also weakened most of the oil and gas projects [48].

Throughout the world electricity is the most widely used and desirable form of energy. It is a basic requirement for economic development, national development, meeting the Millennium Development Goals (MDGs) and for an adequate standard of living. As a country's population grows and its economy expands its demand for electrical energy multiplies. If this demand is not met adequately a shortage in supply occurs. This shortage can assume crisis proportions [48].

According to Power Holding Company of Nigeria (PHCN), the existing generation in 2009 was put at a total installed capacity of 8702 MW (77.73% thermal and 22.27% hydro), available capacity of 4825 MW (72.93% thermal and 27.07% hydro) and an operational capacity of 3149 MW (68.2% thermal and 31.8% hydro) with an availability factor of 0.55 MW (PHCN, Annual Report, 2009).

However, the electric power capacity demand by projection in Nigeria would be approximately three-half fold between 2010 and 2020 and seven-half fold between 2010 and 2030, respectively at 7% growth rate while the projected supply by fuel mix shows a similar trend with the demand at both the 7 and 13% growth rates (Table 8). The earlier discussion shows a wide disparity in the energy demand to supply in the country both in the present and the future, necessitating an urgent need for alternative energy source and efficient energy usage in order to avert looming energy crises.

These projections for continued rapid energy growth imply some severe problems for the future-resource depletion, energy degradation, associated environmental problems, fuel shortage etc. Indeed many of these problems are already happening, thus energy conservation is concerned with ways to reduce energy demand, but yet achieve the same objective as before.

Table 7
Commercial primary energy consumption by type (average % of total).

Type	2002	2003	2004	2005	2006	2007	Average
Coal	0.03	0.03	0.03	0.03	0.05	0.05	0.04
Hydro	11.93	14.20	17.39	12.04	17.03	23.90	16.08
Natural gas	184	1.9	4.54	5.5	7.52	8.73	5.17
Petroleum products	85.20	83.87	78.04	82.45	75.44	67.32	78.71

Source: CBN Annual Report (2005, 2007).

2.4. Likely depletion time of Nigeria's conventional energy resources

It is now universally accepted that fossil fuels are finite and it is only a matter of time before their reserves become exhausted. Estimates of reserves of fossil fuels all reach the same conclusion [49].

In a 1997 analysis, Akinbami [12] arrived at the following estimates.

By year 1989, Nigeria's oil reserve is expected to have reached 20 billion barrels and production should have also increased from 1.89 million barrels per day (mbpd) to 2.5 mbpd. This implies that the reserve/production ratio or the depletion time of Nigeria's crude oil if there is no further efforts to increase the reserve and if the production still remains as at the expected 1989 level, may be within the next 25–30 years. Presently, the natural gas reserves stands at 106 trillion cubic feet (tcf) (about 178 billion barrels of oil equivalent) and by 2010, another 60 tcf (about 10 billion barrels of oil equivalent) is expected to have added to the reserves if the drilling activity continues at current levels. This will bring total natural gas reserves to 166 tcf (about 27.8 billion barrels of oil). Production of gas ranges between 2200 and 2500 million cubic feet per day (about 369,000–420,000 barrels of oil per day). The annual capacity of Nigeria's liquefied natural gas (LNG) project is 4.6 million tonnes (41.96 million barrels of oil equivalent per annual). The nation's international trade volume in liquefied natural gas (LNG) is expected to reach about 5.5 billion m^3 (about 33 million barrels of oil equivalent) in 2000 and between 12 and 15 billion m^3 (about 72–90 million barrels of oil equivalent) in 2010. Using the production upper figure which amounts to 153.3 million barrels of oil equivalent per annum, then the depletion time of Nigeria's natural gas may be in the next 180 years. Coal is very abundant in Nigeria and estimate of reserves is over 2.75 billion tonnes of which about 639 million tonnes is proven. As at 1990, production was 157,000 tonnes but this is expected to increase especially with the recent acceptance of Nigeria coal as of high grade value. Assuming an average modest production figure of about 500,000 tonnes per annum and if there is no addition to the proven reserve, this will make the nation's coal depletion time to be 1278 years from now. However, the reserve/production ratio of coal may be less than this bearing in mind that there is that likelihood of increased demand for Nigeria's coal globally.

Akinbami [12] also indicated that a comparison between the historical consumption and supply patterns reveals that the demand for wood (especially fuel-wood) outstrips the natural regeneration of the forestry stock. At the present rate, the nation's forestry stock may well be depleted within 50 years if the trend is allowed to continue.

Extended use of these reserves, worldwide, in the current manner will continue for no more than some decades to come. The need for supplementary or even alternatives that ideally will be non-depletable energy sources have since been recognized but not adequately utilized in developing countries, especially Nigeria. These non-depletable sources are replenishable and are

Table 8
Electric power capacity in Nigeria (supply by fuel mix and demand for 7 and 13% GDP growth).

	Electric power demand											
	2010				2020				2030			
	Demand (MW%)		Supply (MW%)		Demand (MW%)		Supply (MW%)		Demand (MW%)		Supply (MW%)	
Fuel type	7	13	7	13	7	13	7	13	7	13	7	13
Coal	–		0	0		–	6.515	16.913	–		15.815	63.896
Gas		–	13.555	31.935	–	–	37.733	78.717		–	85.585	192.895
Hydro			3.702	3.902		–	6.479	6.479			11.479	11.479
Nuclear		–	0	0	–	–	3.530	11.005	–	–	11.872	36.891
Small hydro		–	40	208		–	140	1.000	–		701	2.353
Solar		–	5	30		–	34	750	–		302	4.610
Wind			0	500			1.471	3.971			5.369	15.567
Total	15.730	33.250	17.303	36.576	50.820	107.600	55.903	118.836	119.200	297.900	131.122	327.690

Source: Energy Emission of Nigeria (2006, 2008).

also referred to as renewable energy sources as they are available in cyclic or periodical basis. These include: solar energy, wind energy, biomass, hydropower, etc.

3. Renewable energy resource in Nigeria

As we are facing energy resources shortages around the world, there is an urgent need to develop a more sustainable energy system to cater for growth. The use of renewable energy (RE) sources is one of the feasible options. Nigeria is amply endowed with RE sources and is environment-friendly in nature, but the RE capacities are grossly under-utilized, particularly from biomass to wind energy and solar energy. As seen in quite a number of successful countries in promoting RE such as Germany, Denmark and Japan, strong and long-term commitment from the government is crucial in implementing any kind of policies which will lead to RE development [36].

Nigeria's chance to raise the standard of living for its citizens and stabilize its social, economic and political systems lies in its commitment to increase energy output and utilization starting at the grassroots level. However, Nigeria cannot afford to indulge in the traditional exploitation of depleting energy sources such as wood and fossil fuels. The new paradigm of global environmental sensitivity and the reality of dwindling forest and oil reserve demand that Nigeria's much-needed energy sources must be diversified. The country must focus on the development of renewable and sustainable sources. Sustainable energy development in Nigeria is the key to the stability of the country, in terms of viable economy, social order and political stability [41].

Renewable energy constitutes about 90% of the energy used by the rural population [36]. Nigeria has abundant reserves of renewable energy sources ranging from solar, hydro, wind to biomass, etc. It is derived from non-fossil and non-nuclear sources in ways that can be replenished while its harvesting, conversion and use occur in a way that helps to avoid negative impacts on the viability and rights of local communities and natural ecosystems [50]. Apart from the non-replenishment of the abundant fossil fuels that are present in the country, there is also the great threat to global climate through the release of carbon dioxide, heavy metals and particulates. Waste disposal, accident and the release of waste heat into the environment are also associated with nuclear energy, even though the latter poses no threat of climate modification [48].

There is today increased awareness on the need to consider renewable energy sources in Nigeria, going by the low level of socio-economic development attained through over reliance on fossil fuels in which oil and gas still contribute approximately 95% of the revenue and energy needs. It is useful to observe here that government plans to discourage increased consumption of fuel wood and other combustibles especially among the rural dwellers in the near future in an attempt to preserve the forest and natural ecosystem and thus avert climate threat. Each of the renewable energy resources is briefly considered in the following section.

3.1. Hydropower

From Power Holding Company Nigeria's (PHCN) most recent estimate, the country's outstanding total exploitable hydro potential, are shown in Table 9 currently stands at 12,220 MW. Added to the 1930 MW (Kainji, Jebba and Shiroro), already developed the gross hydro potential for the country would be approximately 14,750 MW. Current hydropower generation is about 14% of the nation's hydropower potential and represents some 30% of total installed grid connected electricity generation capacity of the country [13].

In spite of this hydropower capacity in Nigeria still remains underexploited. It must be observed here that Small HydroPower (SHP) has gained rapid consideration in both the developed and developing economies of the world because of its inherent advantages like in-excessive topography problems, reduced environmental impact, minimal civil works and the possibility for power generation alongside with irrigation, flood prevention, navigation and fishery. As shown in Table 10 about 734 MW of SHP can be harnessed from 278 sites (based on a 1980 survey of 12 of the old states in the federation). The Inter-Ministerial committee on available energy resources however estimated a total SHP potential of 3500 MW representing 23% (approximately) of the country's total hydro potential, if the rest of the country is surveyed [29].

Three of the states surveyed, Plateau, Sokoto and Kano have a total of 30 MW of SHP installed capacity in operation, 21 MW being generated by the Nigerian Electricity Supply Corporation Limited (NESCO) from 6 sites in Plateau State (Table 11). Currently, about 5% of the available SHP capacity is being exploited while the remaining is earmarked for future development.

A cost comparison between small-scale hydro power plants and diesel generators for rural electrification clearly indicates the cost effectiveness of the former. It will therefore be useful for the country if more attention is paid to the exploitation of small scale hydro resources for power generation.

3.2. Wind energy

Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the

Table 9
PHCN estimate of current exploitable hydro power sites in Nigeria installed potential.

Location	River	Install potential capacity (TVIW)
Donka	Niger	225
Zungeru II	Kaduna	450
Zungeru I	Kaduna	500
Zurubu	Kaduna	20
Gwaram	Jama are	30
Izom	Gurara	10
Oudi	Mada	40
Kafanchan	Kongum	5
Kurrall	Sanga	25
Kurra I	Sanga	15
Richa II	Daffo	25
Richa I	Mosari	35
Mistakuku	Kurra	20
Korubo	Gongola	35
Kiri	Gongola	40
Yola	Benue	360
Karamti	Kam	115
Beli	Tar aba	240
Garin Dali	Tar aba	135
Sarkin Danko	Suntai	45
Gembu	Dongu	130
Kasimbila	Katsina Ala	30
Katsina Ala	Katsina Ala	260
Makurdi	Benue	1060
Lokoja	Niger	1950
Onitsha	Niger	1050
Ifon	Osse	30
Ikom	Cross	730
Afokpo	Cross	180
Atan	Cross	180
Gurara	Gurara	300
Mambilla	Danga	3960
Total		12,220

Source: Manohar and Adeyanju [13].

Table 10
Small scale hydro potentials according to states.

State	River basin	Total sites	Hydro power potential total capacity (MW)
Sokoto	Sokoto River	22	30.6
Katsina	Sokoto-River	11	8.0
Niger	Niger	30	117.6
Kaduna	Niger	19	59.2
Kwara	Niger	12	38.8
Kano	Hadejia-Jama're	28	46.2
Borno	Chad	29	20.8
Bauchi	Upper Benue	20	42.6
Gongola	Upper Benue	38	162.7
Plateau	Lower Benue	32	110.4
Benue	Lower Benue	19	69.2
Cross-River	Cross-River	18	28.1
	Total	278	734.2

Source: Manohar and Adeyanju [13].

Table 11
Existing small hydro schemes in Nigeria.

River	State	Installed capacity (MW)
Bagel I	Plateau	1
Bagel II	Plateau	2
Ouree	Plateau	2
Kurra	Plateau	S
Lere	Plateau	4
Lere	Plateau	4
Bakalori	Sokoto	3
Tiga	Kano	6
Total		30

Source: Technical Committee on Quantification of Energy Resources (2004).

earth's surface. Seasonal variations in the energy received from the sun affect the strength and direction of the wind. The ease with which aeroturbines transform energy in moving air to rotary mechanical energy suggests the use of electrical devices to convert wind energy to electricity. Wind energy has also been utilized, for decades, for water pumping as well as for the milling of grains [49].

A wind power station generally comprises wind farms and located in areas with relatively high winds. In the wind map of Nigeria coupled with studies on the wind energy potentials for a number of Nigerian cities show that the annual wind speed is between 2.32 m/s with 4.51 W per square of blade area and 3.89 m/s with 21.97 W per square of blade area for Port Harcourt and Sokoto states respectively ([40]; Sambo, 1987). It is estimated that the maximum energy obtainable from a 25 m diameter wind turbine with an efficiency of 30% at a height of 25 m is about 24.5 MWh/year for Port Harcourt, and 25.7 MWh/year for Lagos. It is 97 MWh/year for Sokoto and 50 MWh/year for Kano. Both cities are in the high wind speed region where the average wind speed is greater than 4 m/s. The Sayya Gidan Gada, 5.0 kWp wind electricity in Sokoto is the only known and still functional wind pump in the country. This shows a great potential in contributing to the energy mix. It is pertinent to say that wind is zero in the Nigeria energy mix in spite large amount of it in Northern Nigeria and coastal states.

3.3. Solar energy

Solar energy is the most promising of the renewable energy sources in view of its apparent limitless potential. The sun radiates its energy at the rate of about 3.8×10^{23} kW per second. Most of this energy is transmitted radially as electromagnetic radiation which comes to about 1.5 kW/m^2 at the boundary of the atmosphere. After traversing the atmosphere, a square metre of the earth's surface can receive as much as 1 kW of solar power, averaging to about 0.5 over all hours of daylight [49]. Nigeria lies within a high sunshine belt and thus has enormous solar energy potentials. The mean annual average of total solar radiation varies from 3.5 kW m^{-2} day^{-1} in the coastal latitude to 7 kW m^{-2} day^{-1} along the semi arid areas in the far North of Nigeria. On the average, the country receives solar radiation at the level of 19.8 MJ m^{-2} day^{-1}. Average sunshine hours are estimated at 6 h per day. Solar radiation is fairly well distributed. The minimum average is about 3.55 kWh m^{-2} day^{-1} in Katsina in January and 3.4 kWh m^{-2} day^{-1} for Calabar in August and the maximum average is 8.0 kWh m^{-2} day^{-1} for Nguru in May [36].

Given an average solar radiation level of about 5.5 kWh m^{-2} day^{-1}, and the prevailing efficiencies of commercial solar electric generators, then if solar collectors or modules were used to cover 1% of Nigeria's land area of 923,773 km^2, it is possible to generate 1850×10^3 GWh of solar electricity per year. This is over one hundred times the current grid electricity consumption level in the country.

Solar electricity may be used for power supply to remote villages and location not connected to the national grid. It may also be used to generate power for feeding into the national grid. Other areas of application of solar electricity include low and medium power application such as water pumping, village electrification, rural clinic and schools power supply, vaccine refrigeration, traffic lighting and lighting of road signs, etc. Several pilot projects, surveys and studies have been undertaken by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD) under the supervision of the Energy Commission of Nigeria [14].

3.4. Biomass energy

Biomass energy refers to the energy of biological systems such as wood and wastes. Biomass energy is an indirect form of solar energy

because it arises due to photosynthesis. The biomass resources of Nigeria can be identified as wood biomass, forage grasses and shrubs, residues and wastes (forestry, agricultural, municipal and industrial) as well as aquatic biomass (Technical Working Group, 2009).

The most common form of biomass energy is fuel-wood. Wood, apart from being a major source of energy in the form of fuel wood, it is also used for commercial purposes in various forms as plywood, sawn-wood, paper products and electric poles. For energy purposes, Nigeria is using 80 million m^3 (43.4×10^9 kg) of fuel wood annually for cooking and other domestic purposes. The energy content of fuel wood that is being used is 6.0×10^9 MJ out of which only between 5 and 12% is the fraction that is gainfully utilized for cooking and other domestic uses. Over the period of 1989–2000, fuel wood and charcoal constituted between 32% and 40% of total primary energy consumption (The Presidency, 1992). In year 2000, national demand was estimated to be 39 million tonnes of fuel wood. About 95% of the total fuel wood consumption was used in households for cooking and for cottage industrial activities such as for processing cassava and oil seeds. The biomass availability as at 1973 was put at 9.1×10^{12} MJ [49], it is expected that the overall biomass resource availability at present is lower than the 1973 figure. This is largely due to the demand of wood also for construction and furniture industries in addition to its uses as an energy source. As for forage grasses and shrubs, estimates show that 200 million tonnes of dry biomass can be obtained from them and this comes up to 2.28×10^6 MJ of energy.

In Nigeria, the majority of the populace depend on fuel wood for their cooking and heating energy needs. This implies continuous felling of trees which if left unchecked will promote the ever increasing problem of desert encroachment and soil erosion. Hence, concerted efforts need to be made in order to develop systems which will greatly reduce the consumption of fuel wood. One approach which will be affordable and acceptable to the rural dwellers is the use of improved wood-burning stoves. The primary aim of this technology is to reduce the consumption of fuel wood through better combustion and through a reduction in heat losses. It is also aimed at reducing the cooking time as well as providing an organized channel for the exit of smoke [15].

4. The role of renewable energy technologies in sustainable development

Renewable energy has an important role to play in meeting future energy needs in both rural and urban areas [16]. The development and utilization of renewable energy should be given a high priority, especially in the light of increased awareness of the adverse environmental impacts of fossil-based generation. The need for sustainable energy development is increased rapidly in the world. Widespread use of renewable energy is important for achieving sustainability in the energy sectors in both developing and industrialized countries.

Renewable energy resources and technologies are a key component of sustainable development for the following main reasons:

- They generally cause less environmental impact than other energy sources. The utilization of renewable energy technologies will help to address the environmental concerns that emerged due to the greenhouse gas emission such as carbon dioxide (CO_2), oxides of nitrogen (NO_x), oxides of sulphur (SO_x) and particulate matters as a result of power generation from oil, natural gas and coal. The variety of renewable energy resources provides a flexible array of option for their use.
- They cannot be depleted. If used carefully in appropriate applications, renewable energy resources can provide a reliable and sustainable supply of energy almost indefinitely. In contrast, fossil fuel resources are diminished by extraction and consumption.
- They favour system decentralization and local solutions that are somewhat independent of the national network, thus enhancing the flexibility of the system and providing economic benefits to small isolated populations.

To seize the opportunities of the role of renewable energy resources in sustainable development, countries should establish renewable energy markets and gradually develop experience with renewable energy technologies. The barriers and constraints to the diffusion of renewable should be removed. The legal, administrative and financing infrastructure should be established to facilitate planning and application of renewable energy projects. Government must play a useful role in promoting renewable energy technologies by initiating surveys and studies to establish their potential in both urban and rural areas. Fig. 5 shows the major considerations for developing renewable energy technologies.

4.1. The policy framework on renewable energy in Nigeria

The Federal Government approved the National Energy Policy (NEP) in 2003 to articulate the sustainable exploitation and utilization of all energy resources. The policy is hinged on private sector development of the energy sector. The key elements in the national policy position on the development and application of renewable energy and its technologies are as follows:

- To develop, promote and harness the renewable energy (RE) resources of the country and incorporate all viable ones into the national energy mix.
- To promote decentralized energy supply, especially in rural areas, based on RE resources.
- To promote efficient methods in the use of biomass energy resources.
- To de-emphasize and discourage the use of wood as fuel.
- To keep abreast of international developments in RE technologies and applications.

4.2. Issues and challenges in promotion of renewable energy technologies in Nigeria

Although there is policy framework that stipulates provision of energy for sustainable energy in Nigeria and the directives have been issued, but the stakeholders have not been advised on how to implement them as strategies and long-term policies, i.e. implementation guidelines are lacking. The contribution of RE to the total energy mix is still small, due to lack of knowledge about their potential and insufficient social and environmental policies and programmes to encourage their use/implementation. Nigeria has found it difficult to implement the existing policies and enforce the laws due to lack of infrastructure. The diffusion of RETs could be hampered by several barriers which are financial, technical, regulatory/institutional and informational in nature that needs to be addressed for the viability of RE development in the country.

4.3. Renewable energy and energy efficiency in sustainable development

To achieve sustainability in the development of renewable energy, it should go along side with energy efficiency. Hence, the relationship between renewable energy and energy efficiency can be illustrated with an equation shown below [51]:

$$\text{Renewable energy} + \text{energy efficiency} = \text{sustainable development}$$

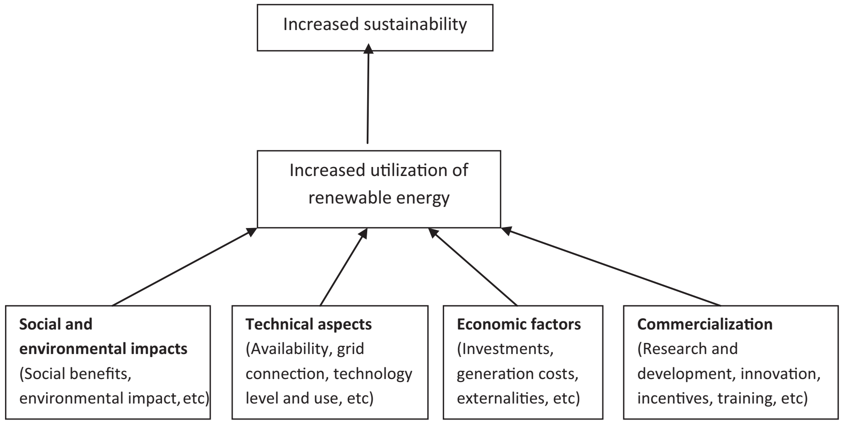


Fig. 5. Major considerations involved in the development of renewable energy technologies for sustainable development.

Renewable energies include wind, ocean wave and tides, solar, biomass, rivers, geothermal (heat of the earth), etc. They are 'renewable' because they are regularly replenished by natural processes and are therefore in endless supply. They also can operate without polluting the environment. Technologies have been developed to harness these energies and such technologies are called renewable energy technologies (RETs) or sometimes also called 'clean technologies' or 'green energy'. Because renewable energy are constantly being replenished from natural resources, they have security of supply, unlike fossil fuels, which are negotiated on the international market and subject to international competition, sometimes may even resulting in wars and shortages. They have important advantages which could be stated as follows:

- Their rate of use does not affect their availability in future, thus they are in exhaustible.
- The resources are generally well distributed all over the world, even though wide spatial and temporal variations occur. Thus all regions of the world have reasonable access to one or more forms of renewable energy supply.
- They are clean and pollution free and therefore are sustainable natural form of energy.
- They can be cheaply and continuously harvested and therefore source of sustainable source of energy.

Unlike the nuclear and fossil fuels plants, which belong to big companies, governments, or state owned enterprises, renewable energy can be set up in small units and is therefore suitable for community management and ownership. In this way, value from renewable energy projects can be kept in the community. In Nigeria, this has particular relevance since the electricity grid does not extend the grid to remote areas and it is prohibitively expensive to extend the grid to remote areas. This presents a unique opportunity to construct power plants closer to where they are actually needed. In this way, much needed income, skill transfer and manufacturing opportunities for small businesses would be injected into rural communities.

4.4. Energy efficiency

Energy efficiency means improvement in practices and products that reduce the energy necessary to provide services like lighting, cooling, heating, manufacturing, cooking, transport, entertainment, etc. Energy efficiency products essentially help to do more work with less energy [52]. Energy efficiency is also defined as essentially using less energy to provide the same service [35]. In this sense, energy efficiency can also be thought of as a supply of resource – often considered an important, cost effective near – to mid-term supply option. Investment in energy efficiency can provide additional economic value by preserving the resource base (especially combined with pollution prevention technologies) mitigating environmental problems.

Energy efficiency improvements have multiple advantages, such as the efficient utilization of natural resources, reduction in air pollution levels and lower spending by the consumers on energy-related expenditure. Investments in EE result in long-term benefits, such as reduced energy consumption, local environmental enhancement and overall economic development. Energy use has environmental impacts, regardless of the source or mechanism. For example, hydroelectric projects affect their local ecological systems and displace long-standing social systems. Fossil fuel power creates pollution in the extraction, transportation and combustion of its raw materials. The long-term storage of the waste products of the nuclear power industry is an issue to be resolved. Cost-effective energy efficiency is the ultimate multiple pollutant reduction strategy [17].

4.4.1. Inefficient utilization of energy in Nigeria

In Nigeria a lot of energy is wasted because households, public and private offices and industries use more energy than is actually necessary to fulfil their needs. One of the reasons is that they use old and inefficient equipment and production processes. The other reasons are unwholesome practices that lead to energy wastage. Some of these are discussed below.

Dominant use of incandescent light bulbs: The use of incandescent bulbs for lighting is energy intensive. Only about 5% of total energy used by an incandescent bulb is converted light energy, the remaining 95% is converted to heat energy [53]. The energy rating of the incandescent bulbs found in the Nigerian market range from 40 W to 200 W, thus we have the ones for 40 W, 60 W, 100 W and 200 W.

A major factor working against the shift from incandescent bulbs to energy saving bulbs is the cost. Energy saving bulbs is far more expensive than incandescent bulbs. The cost of energy saving bulb in the Nigerian market ranges between N800 and N1000. However, some substandard energy saving bulbs could be purchase for about N200. On the other hand, the prices of incandescent bulbs range from N30 to N100.

Energy consumed in Nigeria can be drastically reduced if Nigerians replace their incandescent bulbs with energy efficiency bulbs.

Putting on light to advertise goods: Many Nigerians that sell certain goods such as snack and electrical materials switch on light during the day to draw the attention of people to by their goods. The same way, operators of fast food centres do the similar thing;

they use incandescent bulbs to heat their food and at the same time draw the attention of people to their products. This practice is energy intensive and should be discouraged. In some of the fast food centres, several incandescent bulbs are put on at the same time for aesthetic purpose and to create illumination during the day. These houses could have been built in a way that they use the natural light during the day.

Switching on outdoor lighting during the day: Many Nigerians do not put off their outdoor lighting during the day. This is particularly very common in commercial and residential areas in many major cities in Nigeria. Even in public institutions such as universities, government ministries were also found to have their outdoor lighting switched on during the day. A lot of energy can be saved if Nigerians cultivate the habit of putting off their outdoor lighting in the day time. Energy saved from using the natural light instead of light bulbs during the day can be made available for use in offices and for industrial activities.

Industrial activities in residential areas: Many cities in Nigeria are not properly planned. The practice of building industries in residential areas is unhealthy for power supply for residential use. With this kind of practice, utilities providing electricity are not able to plan on how to allocate energy to the various sectors. More also, because of the high energy consumption of the equipment used in the industries, the equipment exert so much stress on the PHCN facilities which were initially installed to serve residential areas. In this kind of system, it is difficult to allocate energy for the two sectors in a way to maximally satisfy everybody. It is also difficult for utilities to do load shifting.

Setting appliances on standby mode: Many Nigerians do not know leaving appliances on standby mode, the appliances still consume energy. Putting an electrical appliance on standby mode is not the same thing as putting it off. Electrical equipment consumes energy when on standby mode. Although the energy they consume is not the same as when they are switched on, but putting them off when not in use can save some measure of energy. Consumers should be appropriately informed by the manufacturers of the energy electrical appliances at standby mode. A good way to do this is to inscribe it on a label and stick them to the appliances.

Simultaneous use of multiple appliances in public buildings: This is a very common practice among public officers in Nigeria, especially the senior staff. In one department or building, you will find refrigerators and air conditioners at the same time in all offices, even those of junior staff. It is a common practice to find out that in government offices, you will find a refrigerator, air conditioner, television set, photocopy machine, desktop computers, fans, electric kettle and incandescent bulbs, and in many cases these appliances are switched on at the same time. You go to another office in the same department or building, you find similar things. The reason for this practice could be that public officers do not pay individually for electricity and thus they are not conscious of the way the use energy. Also, it has been revealed that many government buildings are not metered; thus government officers are not accountable to the energy they use during office hours.

In university hostels, occupants use all kind of electrical materials and they do not have restriction on the kind of equipment they use. It is a common practice for students to use all kind of electrical heating equipment for cooking in student hostels. The use of particular heating equipment popularly call “hot plate” in student hostels is very energy intensive and should be discouraged. Individual rooms in student hostels are not metered; this encourages wastage as they are not held accountable for the energy they use.

Leaving appliance on when not in use: It has been revealed that many Nigerian do not put off their appliances when they are not in use. This practice can lead to significant wastage of energy in residential, private and public buildings. The reason for this could be that many Nigerians do not really pay for the electricity they consume. In many houses, the meters installed by PHCN are no longer functioning. What PHCN officials do is to place these houses on estimated bill. This practice encourages the wastage of electricity, since they do not really account for what they consume.

Multiple use of inefficient heating equipment: The use of heating equipment for cooking and heating water should be discouraged in the residential and private buildings. Government should encourage the use of solar heaters. Heating equipment consume about 60% of the energy used in houses. In places like hotels where several water heating equipment are installed in several rooms sometime numbering up to 100 rooms or more, the use of solar heaters in these buildings will help to save a lot of energy.

Purchase of second-hand appliances: The Nigerian market is flooded with all kinds of second-hand appliances. Over 90% of Nigerian use one second-hand product or the other. They are cheaper compared to the new ones. Many Nigerians are on the opinion that second-hand products are more durable than the new ones. This assertion could be based on the fact that there are a lot of substandard goods in the market and the second-hand goods tend to last longer than them. Many of the second-hand products come from European and North American countries and they may have been manufactured long time ago. The efficiency of these products is quite doubtful and the possibility exists that they may have been rejected by the former users to purchase more recent and efficient appliances. The second-hand market need to be further studied to direct policy that will address the situation.

4.4.2. Barriers to energy efficiency development in Nigeria

The following are barriers to the development of energy efficiency in Nigeria.

Lack of policy and legislation: Lack of policy and legislation to address the inefficient use of energy is a very key barrier to the development of energy efficiency. Policy and legislation will help to change behaviour towards an energy efficient economy. Private and public institutions should be encouraged to make their own policy to promote the efficient use of energy. The government can make it mandatory for public, large and small scale private organizations to establish an energy management department or unit.

Lack of awareness: Many Nigerians in public and private sectors are not aware of energy efficiency practice. Hence, awareness creation will go a long way to help people understand the concept and change their behaviour.

Lack of trained personnel and energy efficiency professionals: Inadequate trained personnel and professional is another factor inhibiting the development of energy efficiency. Nigeria as a country lack adequate energy efficiency experts that will drive the development of the concept and policy that will promote energy efficiency.

Importation of used machines: The proliferation of imported secondhand appliances may hinder the use of efficient appliances. The reason is that these secondhand equipments are cheap and easily available, the new and efficient ones may be unable to compete with them in the market.

Lack of research materials on energy efficiency: There is lack of research materials and data that will guide the development of policy that will strengthen the efficient use of energy. Also there is lack of material to conduct training on energy efficiency.

Inefficient metering system and low electricity pricing: The metering system in Nigeria is very inefficient and does not encourage consumers to pay the correct amount for the energy they consume. Many people that still use the old meters are now on estimation since these meters are faulty. The use of prepaid meters which was recently introduced by the PHCN will help change the behaviour of consumers to use energy efficiently.

Proliferation of inefficient equipment and desire to minimize initial cost: The desire to minimize initial cost force many consumers to

purchase cheap and inefficient appliances. For example, the cost of energy saving bulbs in the Nigerian market is about N800 compared to an incandescent bulb which cost about N40. Many consumers will prefer to go for the cheaper ones not minding the long-term benefit of using efficiency bulbs.

Low income: About 70% of Nigerians leave below the poverty line of $2 per day. Many are not able to afford the cost of efficiency appliances which are sometime more expensive than the less efficient ones.

4.4.3. Energy conservation vs. energy efficiency

The need for energy is increasing and outstripping its supply. Therefore, and in view of these circumstances primary energy conservation, rationalization and efficient use is an immediate need. Getting all the possible energy from the fuel into the working fluid is the goal of efficient equipment operations. This saves money, produces higher productivity and not only this, it also influences the safety and life of the equipment and reduces pollution [54]. Steps taken to minimize energy consumption, or to use the energy more effectively, are steps in the right direction to preserve the global environment. Energy conservation measures or recommendations are often referred to more positively as opportunities. Two primary criteria for energy conservation opportunities are that it be easy to implement and that its payback be short. Ease of implementation and payback period have been used to classify Energy conservation opportunities into 3 general categories: maintenance and operation measures, process improvement projects, and large capital projects [17].

The policy goals and concepts will have to be shifted from “energy conservation” to “energy efficiency” and from “energy inputs” to the “effectiveness of energy use” and “energy services”.

Energy conservation and energy efficiency are separate, but related concepts. Energy conservation is achieved when growth of energy consumption is reduced, measured in physical terms. Energy conservation can, therefore, be the result of several processes or developments, such as productivity increase or technological progress.

Energy efficiency is achieved when energy intensity in a specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels. Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies [18].

Energy efficiency is often viewed as a resource option like coal, oil or natural gas. It provides additional economic value by preserving the resource base and reducing pollution.

4.4.4. Strategies towards efficient energy usage in Nigeria

In order to meet up with the energy need of consumers, aggressive energy management strategies should be pursued. The aim of energy management is to reduce the amount of energy that a building consumes. Good energy management starts with building energy efficient houses. The next stage is to identify inefficiencies and agree on actions to improve efficiency. These actions need associated targets and ongoing monitoring to measure their performance [19].

The prominent areas of opportunities for energy conservation generally and particularly in office and residential buildings, industrial set-up/manufacturing processes are facilities such as: Ventilating air-conditioning equipment for space cooling (HVAC); lighting and illuminating devices; power generating machines for electrically operated equipment, such as pumps, fans and domestic water heating appliances.

Office and residential buildings: Energy conservation in office and residential buildings actually entails ways of minimizing energy usage in these buildings; this could only be achieved through some measures to be applied to the functional energy usage system such as air-conditioning – space cooling/heating, lighting, electrically operated machines such as motors, pumps, elevators, duplicating machines, water heaters, etc. Up to 50% of the energy used up in the office building and residential buildings could be recovered through such measures as optimum building design [55] more efficient and water distribution systems, improved heating efficiencies for various heating purposes – domestic water heating etc., improved lighting design, energy auditing and integrated design procedures, ventures for alternative energy sources [56] solar, biomass, wind, etc.

The energy efficient housing design principles are based on the idea of using natural conditions to the best advantage and they encompass all the available techniques of creating a “healthy” interaction between indoor and outdoor climatic conditions in buildings [20]. Therefore, energy efficient houses should recognize the following [21]:

- Proper building orientation and symmetry. Building design should permit most of the spaces to be day lighted. Using day lighting reduces energy consumption by replacing electric lights with natural light. Buildings designed for day lighting typically use 40–60% less electricity for lighting needs than do conventional buildings.
- Provision of enough windows for cross ventilation. In very hot climates ventilation is very important. This will go a long way in reducing the use of air conditioners at homes and offices. Although sunlight and daylights are free and readily accessible, however, their use without causing glare and overheating can be difficult. Glare can be avoided by using window sills, louvers, reflective blinds and other devices to reflect light deep into the buildings. Thus windows with selective glazing that transmit the most visible light while reducing solar heat should be favoured.
- Selection of suitable building materials. The walls and floor act as thermal mass to store the heat gained. Therefore hollow blocks and bricks should be used as much as possible. The shape of a building is also important from an energy point of view. A tall, slender building has a high surface area to volume ratio. Ideally a building should be compact, with a low surface area to volume ratio, since the building’s surface is the element through which the heat transfer occurs.

Relamping: Relamping means substituting one lamp for another to save energy. New fixtures are available which produces superior energy savings, reliability and longevity compared with incandescent lamps. Compact Fluorescent Lamps (CFLs) are generally considered best for replacement of lower incandescent lamps at homes, offices, commercial and industrial outfits. These lamps have efficacy ranging from 55 to 65 lumens W^{-1}. The average rated lamp life is 10,000 h, which is 10 times longer than that of a normal incandescent. They offer excellent colour rendering properties in addition to the very high luminous efficiency. Typical energy efficient replacement options, along with the percent energy saving, are given in Table 12.

Manufacturing and industrial processes: Three prominent broad areas had been identified for energy conservation measures in manufacturing and industrial processes. Dubin and Long [18] itemized these as improved house-keeping, recovery of wastes and technological innovations.

- *Improved housekeeping*: Improved house keeping with such factors as furnace maintenance, adjustment of lighting system operations, use of daylight, improving space conditions for lighting and improving lamp and fixture efficiency are quantifiable measures of energy conservation.

Table 12
Energy savings by the use of high efficacy lamps.

Sector	Lamp types		Power saving	
	Existing	Proposed	W	(%)
Domestic/commercial	GLS 100 W	CFL[a] 25 W	75	75
Industrial	GLS 13 W	CEL[a] 9 W	4	31
GLS 200 W	Blended 160 W	40	20	
TL 40 W	TLD 36 W	4	10	
Industrial/commercial	HPMV 250 W	HPSV 150 W	100	37
HPMV 400 W	HPSV 250 W	150	35	

Source: Ekeh et al. [19].
[a] Wattages of CFL includes energy consumption in ballasts.

- *Recovery of waste*: This forms a significant savings in energy through recovery of waste heat – flue gas, exhaust steam, co-generation of electricity, etc. Heat reclamation is the recovery and utilization of energy that is otherwise wasted, which can be a substitute for a portion of the new energy that would normally be required for heating cooling and domestic hot water system. Heat recovery conserves fuels, reduces operating costs and reduces peak loads.
- *Technological innovation*: this border on major redesign of processes and products to yield greater efficiency of cycle operations.

Installing lighting control systems, in bathrooms, stores and bedrooms: Lighting controls are devices for turning lights on and off or for dimming them. The simplest type is a standard snap switch or on-off switch. Presently majority of our lights are controlled by snap switches. This is the simplest and the most widely used form of controlling a lighting installation. Its initial investment is extremely low, but the resulting operational cost may be high. It does not provide the flexibility to control the lighting, where it is not required. There is the need to install lighting control systems such as are photocells, timers, occupancy sensors and dimmers in bathrooms, stores, bedrooms and other not frequently used areas.

Street light control: Street lighting accounts for more than 50% of all electricity consumed. Of this value about 50% or more of the energy is wasted by absolute equipment, inadequate maintenance, or inefficient use. Table 13 shows the energy savings potential by the use of efficiency lamps for street lighting. Saving lighting energy requires either reducing electricity consumed by the light source or reducing the length of time. The following light control systems can be adopted at the design stage:

- Grouping of lighting system, to provide greater flexibility in lighting control. This could be achieved by mechanical or electronic time clocks.
- Installation of microprocessor based controllers. In this method the use of microprocessor/infrared controlled dimming or switching circuits is employed. The lighting control can be obtained by using logic units located in the ceiling, which can take pre-programme commands and activate specified lighting circuits. Advanced lighting control system uses movement detectors or lighting sensors, to feed signals to the controllers.
- Installation of "exclusive" transformer for lighting. Most of the problems faced by the street and open court lighting equipment and gears is due to voltage fluctuations. Hence, the lighting equipment has to be isolated from the power feeders. This provides a better voltage regulation for lighting. This will reduce the voltage related problems, which in turn increases the efficiency of the lighting system.
- Installation of servo stabilizer for lighting feeder. Whenever, installation of exclusive transformer for lighting is not economically attractive, servo stabilizer can be installed for the lighting feeders. This will provide stabilized voltage for the lighting equipment. The performance of gears such as chokes, ballasts, will also be improved due to the stabilized voltage. This set up also provides the option to optimize the voltage level fed to the lighting feeder. In many plants, during the non-peak hours, the voltage levels are on the higher side. During this period, voltage can be optimized, without any significant drop in the illumination level.

Table 13
Energy saving potential by the use of high efficiency lamps for street lighting.

Existing lamps			Replaced units			Saving	
Type	W	Life	Type	W	Life	W	(%)
GLS	200	1000	ML	160	5000	40	7
GLS	300	1000	ML	250	5000	50	17
TL	2 × 40	5000	TL	2 × 36	5000	8	6
HPMV	125	5000	HPSV	70	12,000	25	44
HPMV	250	5000	HPSV	150	12,000	100	40
HPMV	400	5000	HPSV	250	12,000	150	38

Source: Ekeh et al. [19].

Installing lighting control systems, in bathrooms, stores and bedrooms: Lighting controls are devices for turning lights on and off or for dimming them. The simplest type is a standard snap switch or on-off switch. Presently majority of our lights are controlled by snap switches. This is the simplest and the most widely used form of controlling a lighting installation. Its initial investment is extremely low, but the resulting operational cost may be high. It does not provide the flexibility to control the lighting, where it is not required. There is the need to install lighting control systems such as are photocells, timers, occupancy sensors and dimmers in bathrooms, stores, bedrooms and other not frequently used areas.

Voltage reduction: Voltage reduction is a technique of intervention that is mainly used when there is a severe power shortage. Although voltage reduction is mainly used in emergency situations, some utilities use it as a method of reducing the demand on the system during normal operation. If used only at peak times, voltage reduction falls into the category of peak clipping. If it is used for an extended period, it falls into category of strategic conservation. Investigations revealed that reducing the nominal voltage by 10% can result in 7–18% decrease in the consumer load. This magnitude of saving would allow for the deferral of capital expenditure on new generation and network upgrades. Another advantage of this method of emergency conservation is that if the load is reduced, the distribution line losses will also be reduced. The distributor would not need to buy as much energy to meet its consumers' needs. The main disadvantage of using the voltage reduction method is that consumers, especially at the end of the distribution line, may experience low quality of supply due to under voltage. Installing capacitors for use in conjunction with voltage can improve this.

Demand side management (DSM) and energy conservation measures (ECM): Demand side management and energy conservation measures are processes of managing the consumption of energy. These processes are designed to optimize the available and planned generation resources [22]. It has been reported that a lot of energy is lost at the consumers' side of the grid. Study by Aderibigbe and Olukoya [23] shows that Nigerians waste a lot of electricity with each household wasting at least 100 W at a time (total nation-wide = 200–300 MW). Demand side management and energy conservation measures therefore refer to actions taken on the customer's side of the meter to change the amount or timing of energy consumption. They offer solutions to problems such as: load management, energy efficiency, strategic conservation and related activities. Consumers should be educated on the need and incentive to reduce their demand at peak times. Methods that the consumers can use to reduce energy consumption and wastages include the following.

Retrofitting ballasts and lighting for lower costs and higher efficiency. Fluorescent lights need ballasts (that is, devices that control the electricity used by the unit) for starting and circuit protection. Ballasts consume energy. Existing fluorescent ballasts can be replaced with improved electromagnetic ballasts and electronic ballasts.

This could raise the efficiency of the fixture by 12–30%. The new improved electromagnetic ballasts reduce ballast losses, fixture temperature and system wattage. Since they operate at cooler temperatures, they last longer than standard electromagnetic ballasts.

Electronic ballasts operate at a very high frequency that eliminates flickering and noise. They are even more efficient than improved electromagnetic ballasts. Electronic ballasts have the following advantages over the traditional magnetic ballasts: Energy saving up to 35%, light instantly, improved power factor, operates on low voltage load, less in weight and increases the lifespan of the lamps. These advantages outweigh the initial investment (higher costs when compared with conventional ballasts). The lifespan is high especially when used in a lighting circuit fitted with an automatic voltage stabilizer.

Circuit breaker tariff: The capacity of a residential consumer to contribute to the system maximum demand is limited by installing a low circuit breaker rating. A consumer can choose from a range of circuit breaker ratings, e.g. 20, 30 or 60. The monthly basic charge increases with the circuit breaker rating. The kWh cost can also be set at different levels depending on the circuit breaker size. Consumers can then choose the best option for themselves based on their own financial situation. If they choose a low value circuit breaker, they must plan their use of electricity in such a way that they do not trip the circuit breaker. If they decide at some stage that they need a higher value circuit breaker, they can apply to the distributor for an upgrade. Circuit breaker tariffs fall into the category of strategic conservation. The main advantage of this method is that it trains the consumer to use energy efficiently.

Use of renewable energy source: Renewable energy is a technology that makes use of the naturally occurring substances such as wind, water, sun and biomass to generate electricity. They are renewable by virtue of their limitless nature. Wind, for instance, will always blow. There will always be sunlight. Therefore, there is the need to incorporate renewable energy sources, especially solar panels into the distribution networks. The use of solar cell technology will go a long way to save energy from public utility supply. A solar powered street lighting system that is totally independent of the utility power supply should be incorporated in our distribution system. Solar panels are connected in such a manner to charge maintenance free battery with sufficient capacity to light the streets and/or traffic signals. Solar water heaters should be encouraged. Solar generated electricity is environmentally friendly as it is devoid of the following:

- Emission of greenhouse gases-global warming.
- Emission of ozone depletion gases.
- Noise, smoke and general nuisance from domestic diesel generators right into our ears, faces and lungs.

Energy conservation measures in transportation: These include increasing the efficiency of the vehicle system, proper vehicle maintenance for better engine performance, use of alternative energy source, e.g. fuel-cells, etc.

- *Rationing*: Techniques used in rationing include restricting the uses of an item-for example, forbidding the use of gasoline to power pleasure boats; limiting the quantity available to any consumer; curtailing the hours when an item may be sold; setting a maximum amount a person can spend for an item; and employing a point system, which assigns a point value to a number of articles and permits customers to "spend" a certain number of total points.
- *Improved technology through electric cars*: These are automobiles propelled by one or more electric motors, drawing power from an onboard source of electricity (Wikipedia). Electric cars are mechanically simpler and more durable than gasoline-powered cars, stores its energy on board-typically in batteries, but alternatively with capacitors or flywheel storage devices. Or it may generate energy using a fuel cell or generator; they produce less pollution than do gasoline-powered cars. Energy conservation in electric cars, however, is so important that engineers found a way to recover the heat and use it for other heating purposes.

Energy conservation in power generation and distribution: This involves improvement in energy conversion technology for better efficiency [24], use of thermionic, thermoelectric in, magneto-hydrodynamic generators for better fuel saving.

4.4.5. Renewable energy and energy efficiency as climate change mitigation strategies

The Inter-government Panel on Climate Change (IPCC), a body set up in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) to provide authoritative information about climate change phenomenon, asserts that the warming of the last 100 years was unusual and unlikely to be natural in origin [51]. IPCC has attributed the warming of at least the second half of the century to an increase in the emission of greenhouse gases into the atmosphere. Human activity is largely responsible for the emission of these gases into the atmosphere: CO_2 is produced by the burning of fossil fuels (coals, oil and gas) as well as land-use activities such as deforestation; methane is produced by cattle, rice agriculture, fossil fuel use and landfills; and nitrous oxide is produced by the chemical industry, cattle feed lots and agricultural soils. As humans have increased their levels of production and consumption, greenhouse gas emissions have also increased; since 1750, at the time of Industrial Revolution, CO_2 emission has increased by 31%, methane by 15% and nitrous oxide by 17%. Moreover, the emissions of these gases continue to rise steadily [57].

Energy-efficiency and renewable energy technologies are prominent in most sustainable development programs, for example Agenda 21 (UN 1993). According to the Intergovernmental Panel on Climate Change (IPCC) second assessment report, stabilization of atmospheric greenhouse gas concentrations at levels that will prevent serious interference with the climate system can only be achieved by dramatically increasing utilization of renewable energy supplies. In one IPCC scenario, in which greenhouse gases are stabilized by the year 2050, the share of renewable energy in the global energy balance must increase by tenfold from current levels. In developing countries, the required increase is even more dramatic, estimated at twenty-fold between 1990 and 2050. Further, improvements in energy efficiency and energy conservation can reduce emissions in the shorter term, thus "buying time" for the required changes in energy production [25].

Energy efficiency is not a panacea, but combined with an increased diversification of energy sources and technological advancements, it can make a significant impact in squaring the circle between an increased demand for the services energy provides and environmental protection.

Nigeria is one of the highest emitter of greenhouse gases in Africa. The practice of flaring gas by the oil companies operating in Nigeria has been a major means through which GHGs are released into the atmosphere. Carbon dioxide emissions in this area are among the highest in the world [58]. Some 45.8 billion kilowatts of heat are discharged into the atmosphere of the Niger Delta

from flaring 1.8 billion cubic feet of gas every day [51]. Gas flaring has raised temperatures and rendered large areas uninhabitable. Between 1970 and 1986, a total of about 125.5 million m^3 of gas was produced in the Niger Delta region, about 102.3 (81.7%) million m^3 were flared while only 2.6 million m^3 were used as fuel by oil producing companies and about 14.6 million m^3 were sold to other consumers [26]. The use of renewable energy sources will reduce over dependency on the burning of fossil fuel. Moreover, instead of flaring gas in Nigeria, the gases can be converted to methanol and used as fuel for both domestic and industrial use. With good energy efficiency practices and products, the burning of fossil fuel for energy will be greatly minimized.

5. Conclusions and recommendations

In this study, four economic growth scenarios were considered in the review of the energy requirements. These are the reference scenarios of 7% total GDP growth rate that will ensure the Millennium Development Goals' (MDGs) objective of reducing poverty by 50% of the 2000 value by 2015. The high growth scenario of 10% GDP growth rate in the attempt to eradicate poverty by 2030 and the optimistic scenarios of 11.5 and 13% GDP growth rates that will further increase the rate of economic development.

From the energy outlook of Nigeria, it is very clear that energy demand is very high and is increasing geometrically while the supply remains inadequate, insecure, and irregular and is decreasing with the years; the mix has hitherto been dominated by fossil sources which are fast being depleted apart from being environmentally non-friendly. The energy supply mix must thus be diversified through installing appropriate infrastructure and creating full awareness to promote and develop the abundant renewable energy resources present in the country as well as to enhance the security of supply.

There is clear evidence that Nigeria is blessed with abundant resources of fossil fuels as well as renewable energy resources. The major challenge is inefficient utilization of energy in the country. As a result, there is the urgent need to encourage the evolvement of an energy mix that will emphasize the conservation of petroleum resources in such a manner that will lead to their continued exportation for foreign earnings for as many years to come as possible.

Presentation on the opportunities that are available in conserving energy in our various sectors – office building and residential areas, manufacturing industries, transportation, electricity generation and distribution, electricity equipment and appliances has been made in this work. The various areas where savings in energy can be made have been identified in this study, these include: energy use in heating and ventilating equipments, lighting, electrically operated machines such as pumps, motors, fans and hot water heating. Several guideline and measures have been suggested to conserve energy in these areas and if the guidelines and measures are strictly adhered to, substantive savings in energy will be made.

In order to ensure the sustainability of energy supply and subsequently of the country's sustainable economic development, the government has to intensify further the implementation of renewable energy and energy efficiency programmes. As seen in quite a number of successful countries in promoting RE such as Germany, Denmark, and Japan, strong and long-term commitment from the Government is crucial in implementing any kind of policies which will lead to RE development in particular and sustainable energy development in general.

In this study, it is established that renewable energy and energy efficiency are two components that should go together to achieve sustainable development and climate change mitigation in Nigeria. The need to conserve the present energy generated in the country using energy efficiency products and practices is essential for sustainable development. It is recommended therefore that the country should:

- Develop policies on energy efficiency and integrate them into current energy policies.
- Promote energy efficiency products and practices at the side of end users and energy generation.
- Create awareness on renewable energy and energy efficiency.
- Establish agency to promote the use of energy efficiency products and ensure energy efficiency practices.
- Develop and imbibe energy efficiency technologies.
- Carry out resource survey and assessment to determine the total renewable energy potential in the country as well as identify the local conditions and local priorities in various ecological zones.
- Establish a testing and standards laboratory for RETs similar to the one in South Africa.
- Take advantage of global partnerships such as the REEP initiative of UK, to help the country for creative integration of renewable energy systems.
- Establish renewable energy funding/financing agency like India's IREDA (India Renewable Energy Agency).
- Develop appropriate drivers for the implementation of energy efficiency policy.

In addition to these, the existing research and development centres and technology development institutions should be adequately strengthened to support the shift towards increased renewable energy utilization. Human resource development, critical knowledge and know-how transfer should be in focus for projects development, project management, monitoring and evaluation. Preparation of standards and codes of practices, maintenance manuals, life cycle costing and cost-benefit analyses tools to be undertaken on urgent priority.

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